Near-Real-Time Assimilation of SMAP Soil Moisture Retrievals in the Land Information System

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SMAP Science Team and Early Adopters Team

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Overview

Where we have been:

Assimilation of SMOS soil moisture products into the Land Information System

Where we are now:

Current status of SMAP assimilation in LIS

Where we are going:

Plans for SMAP in CONUS and East Africa

validation of soil moisture analyses

evaluation of impact on NWP

Goals

Assimilate satellite retrievals of soil moisture into a regional (3-km) land surface model (SPoRT LIS running Noah 3.3).

- Take advantage of high-resolution geophysical properties, best available atmospheric forcing, and latest satellite measurements on soil moisture

Predicted impact

- Improved accuracy of high-resolution soil moisture fields
- Better depiction of gradients and structure for coupling with NWP models at convection-allowing resolution (3 km) for regional weather forecasting

Demonstrate impact on:

- LSM soil moisture field
- coupled NWP forecasts

Transition a real-time version of LIS output to end users.

Use experience from SMOS assimilation to implement SMAP.

Short-term Prediction Research and Transition (SPoRT) Center

Mission: Transition unique NASA and NOAA observations and research capabilities to the operational weather community to improve short-term weather forecasts on a regional and local scale.

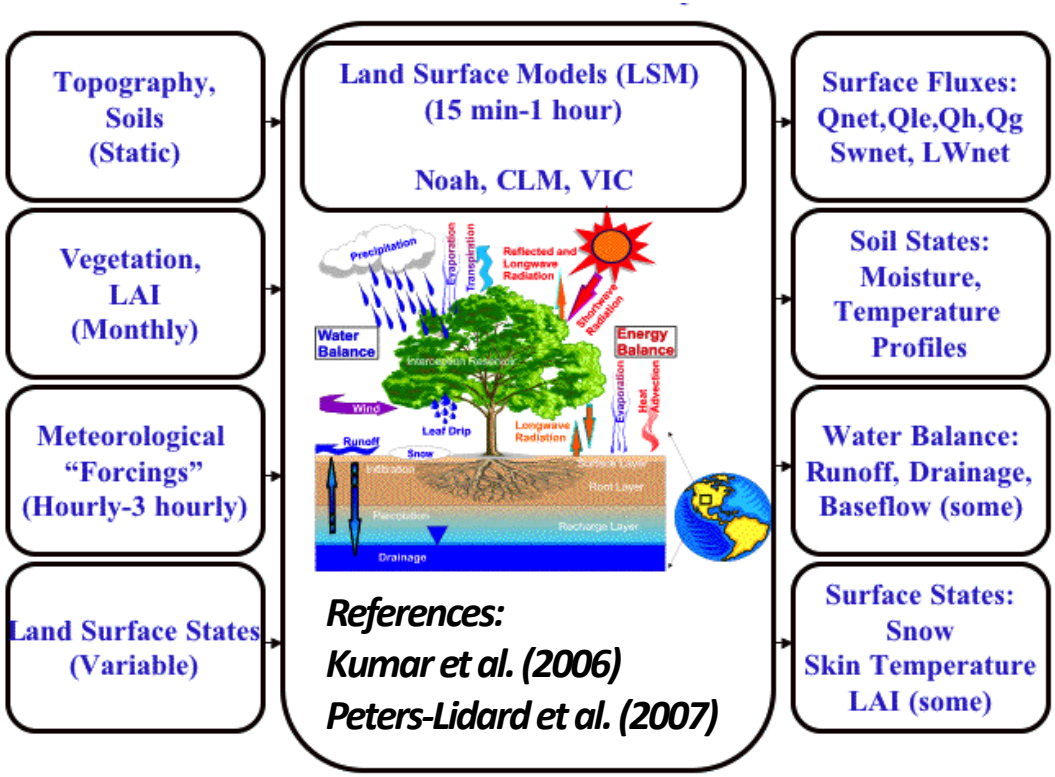
- Close collaboration with numerous WFOs and National Centers across the country
- SPoRT activities began in 2002, first products to AWIPS in 2003
- Co-funded by NOAA since 2009 through Proving Ground activities
- Proven paradigm for transition of research and experimental data to operations

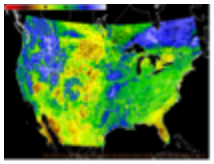
Benefit:

- Demonstrate capability of NASA and NOAA experimental products to weather applications and societal benefit
- Take satellite instruments with climate missions and apply data to solve shorter-term weather problems

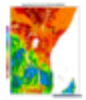
NASA SPORT

Land Information System (LIS)





SPoRT-LIS total column soil moisture displayed in AWIPS II



- Framework for running LSMs incorporating a wide variety of meteorological forcing data and land surface parameters
  - Developed by NASA-GSFC
  - Includes data assimilation capability.
  - Can be run coupled with Advanced Research WRF.
- Using Noah 3.3 Land Surface Model (LSM) within LIS
- SPoRT maintains near-real-time and experimental LIS runs
  - SE US (3-km), shared with WFO's
  - East Africa, shared with Kenya Meteorological Service (KMS)

East Africa LIS domain

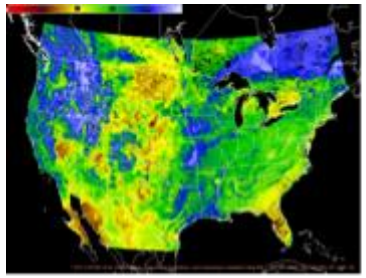
SPoRT Real-time LIS Running Noah LSM

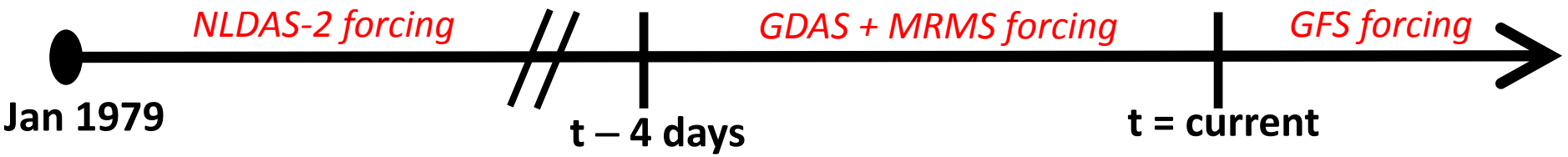
Full Continental U.S. (CONUS) domain with 0.03° (lat/lon) grid resolution

Unique characteristics of SPoRT-LIS:

- Real-time S-NPP/VIIRS Green Vegetation Fraction
- Albedo scaled to input vegetation
- Restart simulation strategy to produce real-time output (timeline below)
- SPoRT-LIS ingested and displayed in AWIPS II at select NOAA/NWS weather forecast offices
- Land surface variables available to initialize modeling applications (WRF and STRC/EMS/UEMS)

Current SPoRT-LIS CONUS domain, as displayed in AWIPS II





SPoRT-LIS Evaluations

SPoRT-LIS for improving situational awareness

- 2014 assessment: NWS Huntsville, Houston, Raleigh
- 2015 evaluation: NWS Tucson, Albuquerque, and Huntsville
- Part of Summer 2015 evaluation focused on GPM/IMERG precipitation (Smith talk 9.6, *30th Hydro*, Thursday 2:45pm)
- Disseminated select soil moisture grids and change fields
- Forecaster surveys and blog posts to highlight product utility
- Applications included:
  - Assessing drought and USDM drought categories
  - Monitoring soil moisture to help evaluate flooding concerns
  - Examining soil moisture around wildfires
  - Evaluating risk for blowing dust from convective outflows

SPoRT-LIS Evaluation:

Soil Moisture Associated with Wildfire (NWS ABQ)

(left) 1-yr change ... ric soil moisture soil moisture, val ... 5. NWS Albuquerqu ...

[Photo credit: Dave DuBois, NM state climatologist]

SMOS and SMAP

- L-band radiometers (and radars) can be used to estimate soil moisture near the surface
  - Compared to higher frequency instruments:
    - Sees deeper in the soil (~1-5 cm)
    - Better vegetation penetration
    - Higher sensitivity (accuracy)
    - Larger footprint (~36 km)

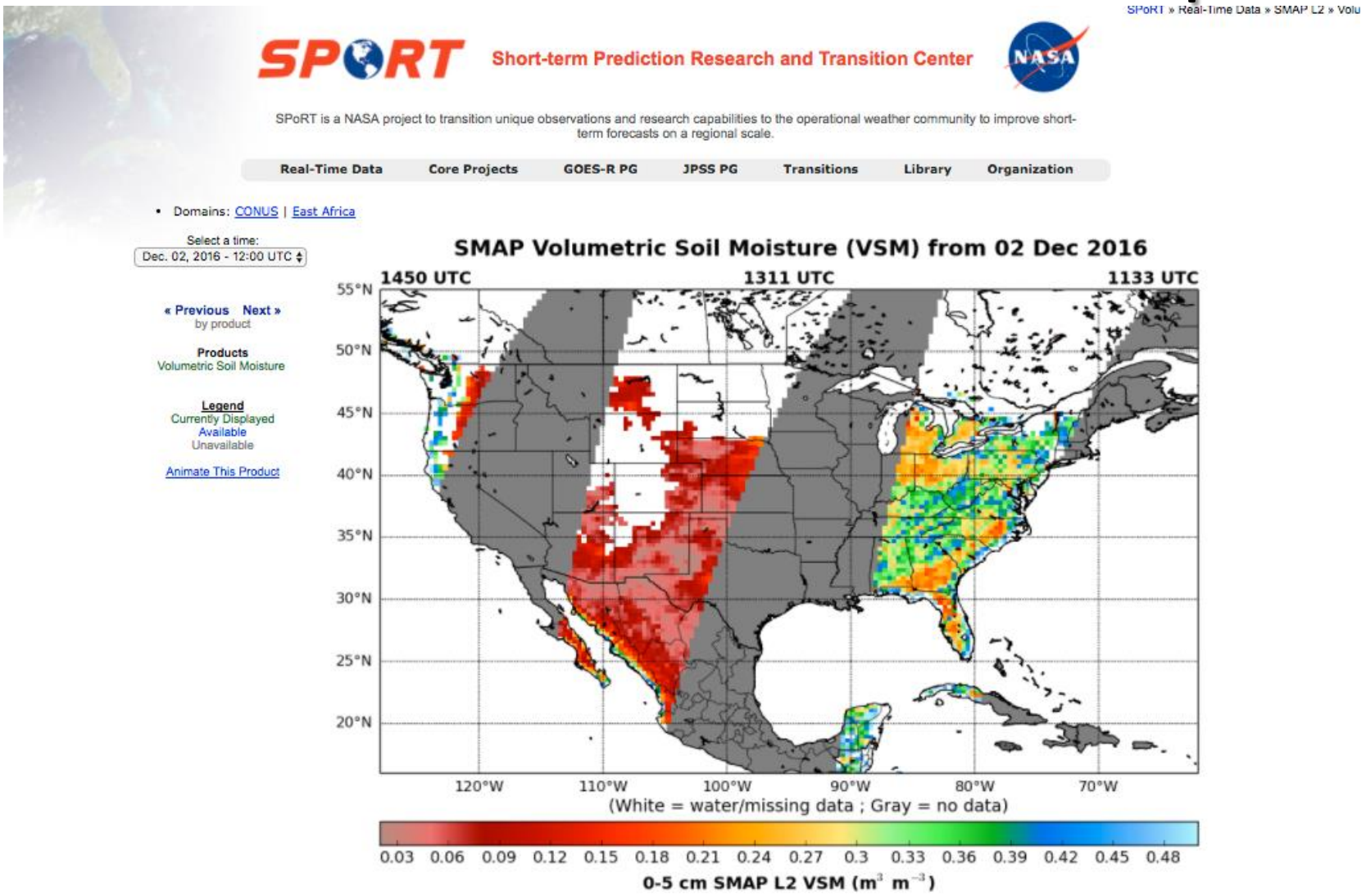
- Tested retrievals from Soil Moisture and Ocean Salinity (SMOS) satellite
  - IEEETGRS paper (November 2016)
- Implementing assimilation of NASA Soil Moisture Active/Passive (SMAP) retrievals
  - SMAP has higher resolution product but due to failure of radar, time period is limited to a few months.

Soil Moisture and Ocean Salinity

Soil Moisture Active/Passive

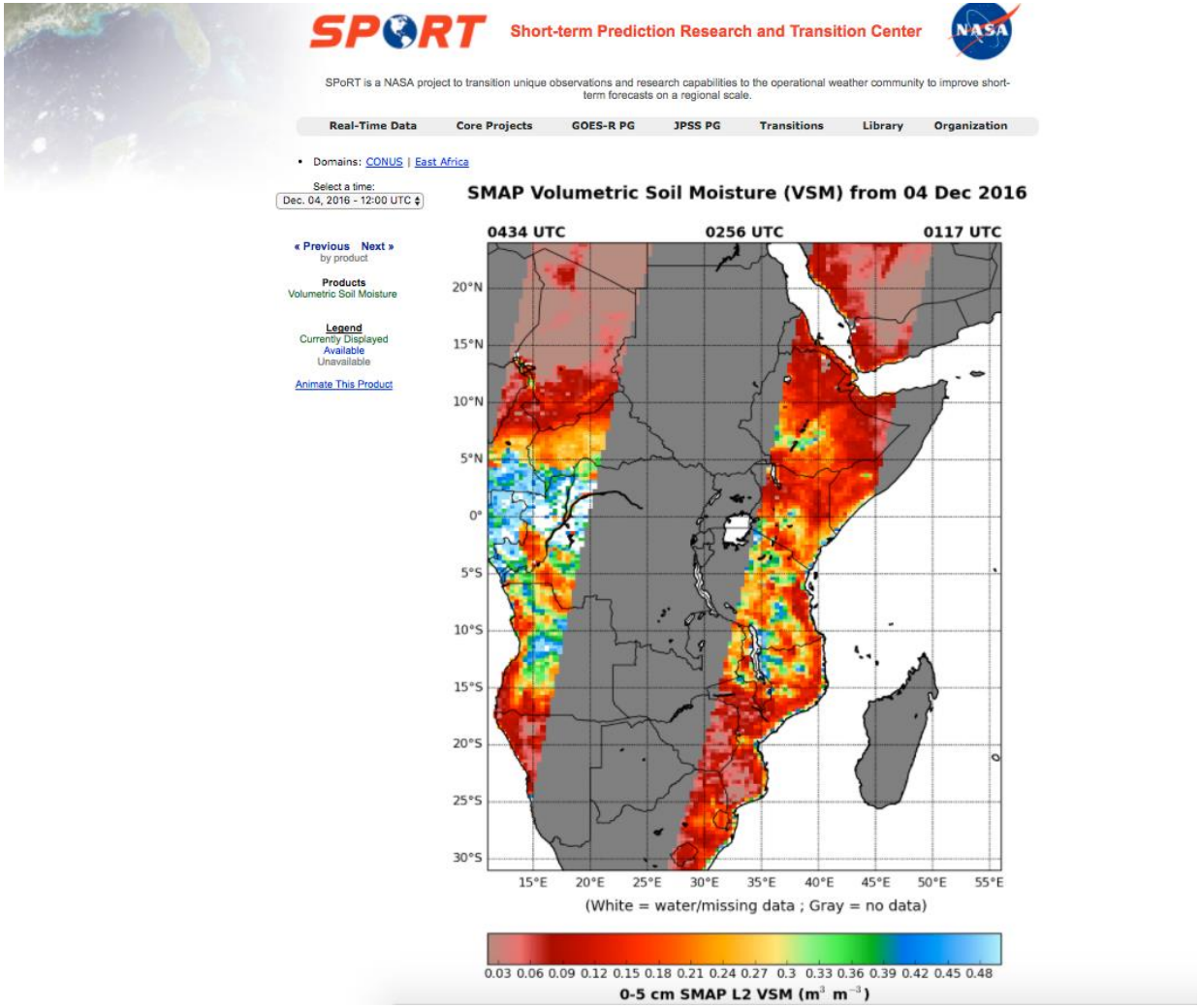
Name	AMSR-E	SMOS	SMAP		
Agency	NASA/JAXA	ESA	NASA		
Launch	2002	2009	Jan. 2015		
Orbit	Polar	Polar	Polar		
Sensor Type	Passive	Passive	Passive	Active (Failed July 2015)	Combined (limited duration)
Frequency	6.9 GHz (C-band)	1.4 GHz (L-band)	1.41 GHz	1.2 GHz	
Resolution	56 km	35-50 km	36 km	**3 km**	9 km
Accuracy	6 cm^3/cm^3	**4 cm^3/cm^3**	**4 cm^3/cm^3**	6 cm^3/cm^3	**4 cm^3/cm^3**

Near-Real-Time SMAP L2 Maps



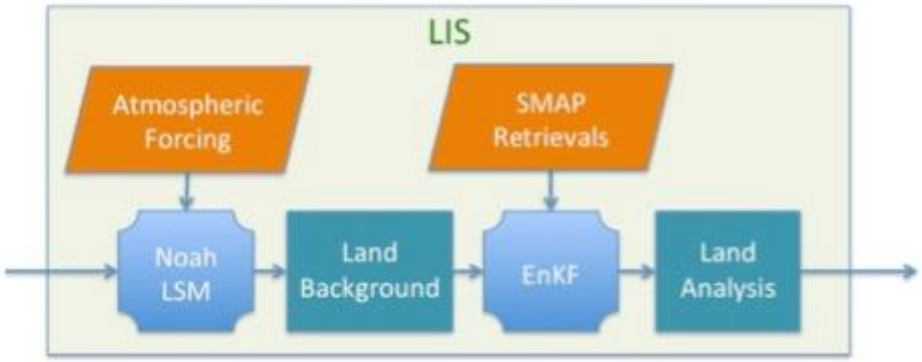
http://weather.msfc.nasa.gov ->Real-Time Data->SMAP Soil Moisture->CONUS

Near-Real-Time SMAP L2 Maps



http://weather.msfc.nasa.gov ->Real-Time Data->SMAP Soil Moisture->East Africa

Data Assimilation in LIS



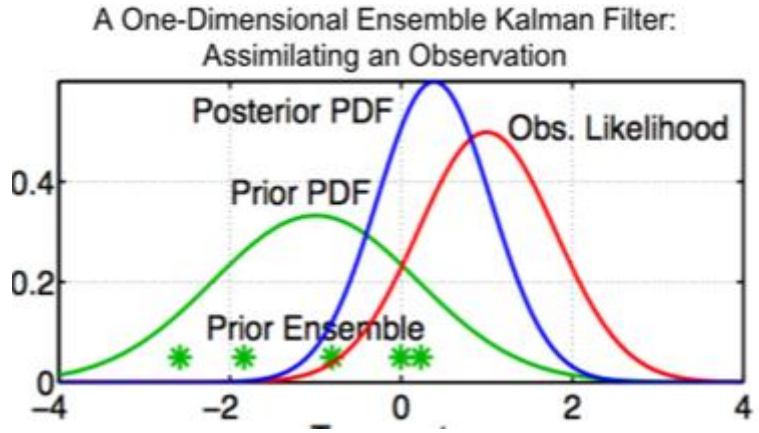
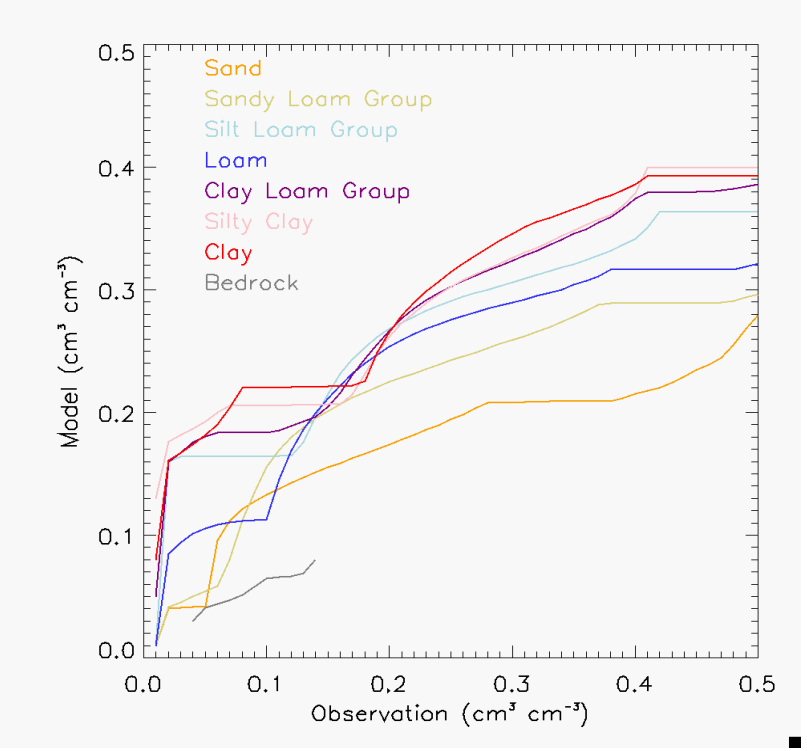


Figure from J. Anderson, NCAR.

- Uses Ensemble Kalman Filter in LIS
- Combines Background (Model) and Observations (Satellite Retrievals), weighted by their uncertainties, to provided a new analysis
- Observation operator relates the top model layer of soil moisture (0-10 cm) to the bias-corrected observations (~5 cm).
- Better depiction of top layer can improve deeper layers through infiltration and diffusion.

Bias Correction

Correction Curves By Soil Type



- Assimilation systems assume unbiased observations
- LIS can apply point-by-point correction curves. Many implementations generate climatologies of model and obs at each grid point.
- We have implemented CDF matching aggregated by soil type
  - Described for SMOS in Blankenship et al. 2016 (IEEE TGRS)
  - Idea is to let the observations influence the model climatology
- Other methods will be explored including using only nearby points
- Using a thinner soil moisture layer may reduce forward operator error and subsequently the magnitude of bias corrections

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SMAP soil moisture assimilation

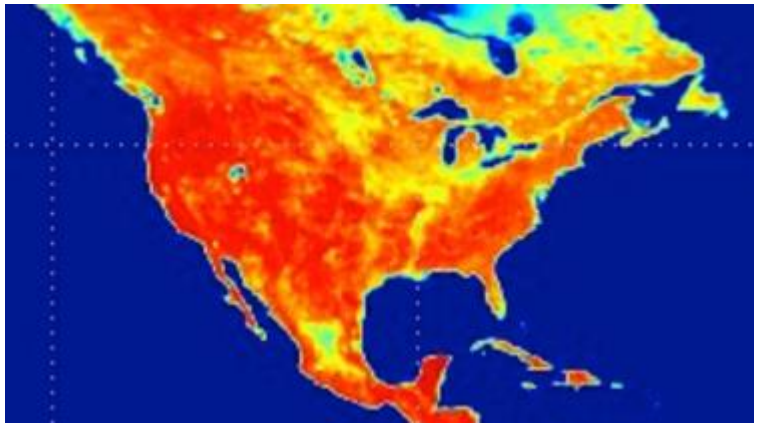
- Original plan: assimilate combined active/passive (L2) retrievals (9 km)
- SMAP radar failed July 2015
- Current status: assimilating passive (L2) retrievals (36 km)

  into the 3-km grid
  - Simple downscaling based on model background to reduce ”blockiness”
- Future plans: SMAP L2 Enhanced Product

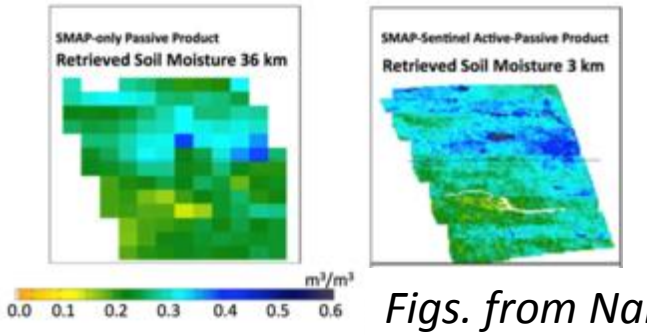
  from SMAP Science Team
  - Backus-Gilbert interpolation
  - 25 km expected resolution
  - 9 km grid
- Possible use of Sentinel-Enhanced

  1-3km product (depending on

  coverage and update frequency)



SMAP Enhanced T_b (Backus-Gilbert)



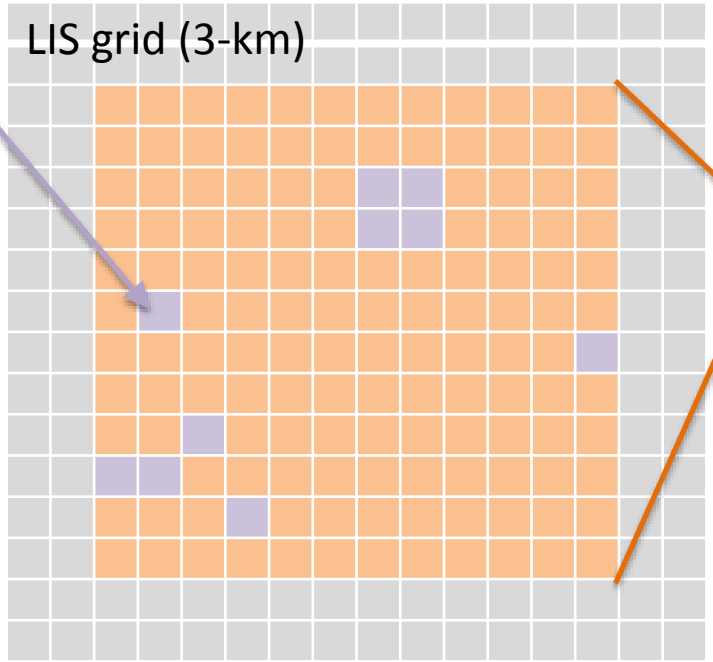
Figs. from Narendra Das

Sampling Strategy

- Level 2 data are available on 36-km EASE grid
- To take advantage of high resolution geophysical properties (topography, vegetation, soils), running model at 3-km
- SMAP observations are assimilated at each model grid point in their FOV

Some QC applied on LIS grid
Depends on LSM/variable (e.g. Noah3.3+soil moisture)

- Precip (changed to 1 mm/hr)
- Frozen ground
- Snow on ground
- GVF>0.7
- Extreme values (new in LIS 7)
- "Forest" land class



SMAP (passive)
36-km cell

Data flag-based QC applied at observation resolution

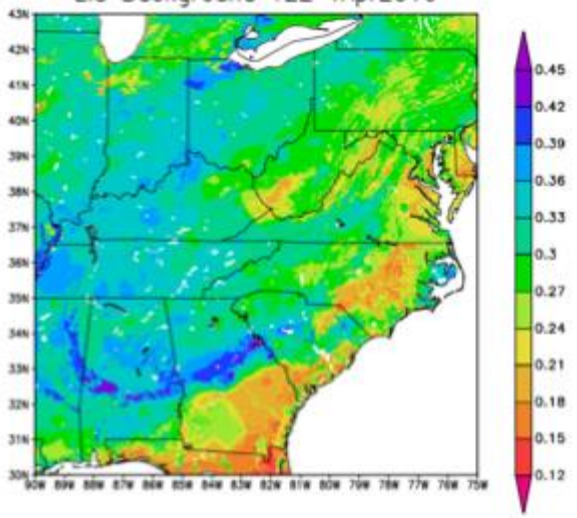
- **Retrieval Quality Flag**
- Vegetation Opacity
- Vegetation Water
- Frozen Ground Fraction

Bias correction will be applied on LIS grid.

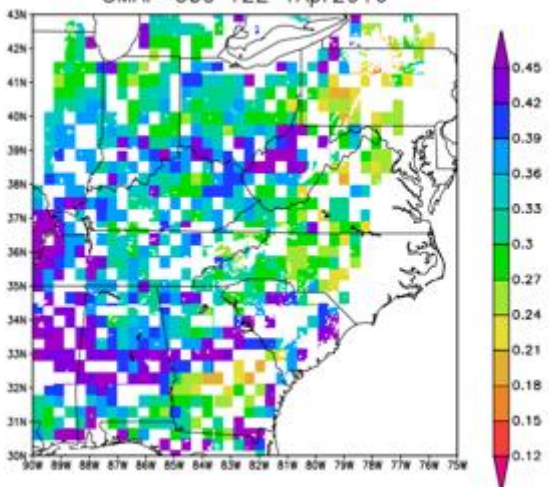
SMAP and LIS grids are not aligned. Near boundaries, keep only one observation per cell (closest good ob)

SMAP Data Assimilation Example

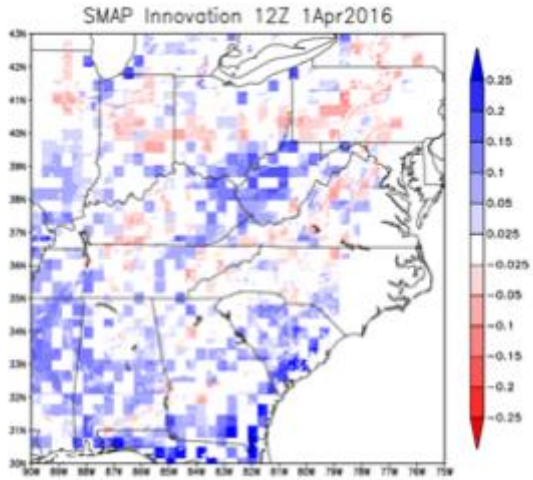
1. LIS Background 12Z 1Apr2016



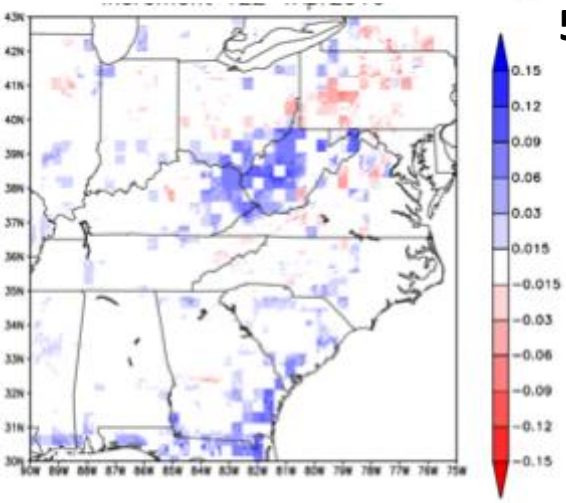
2. SMAP Obs 12Z 1Apr2016



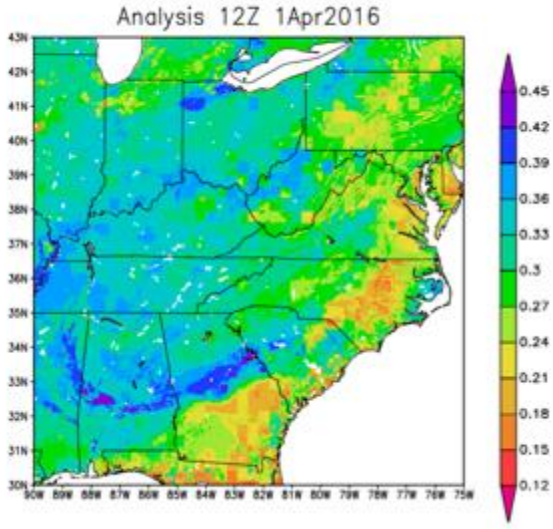
3. SMAP Innovation 12Z 1Apr2016



4.

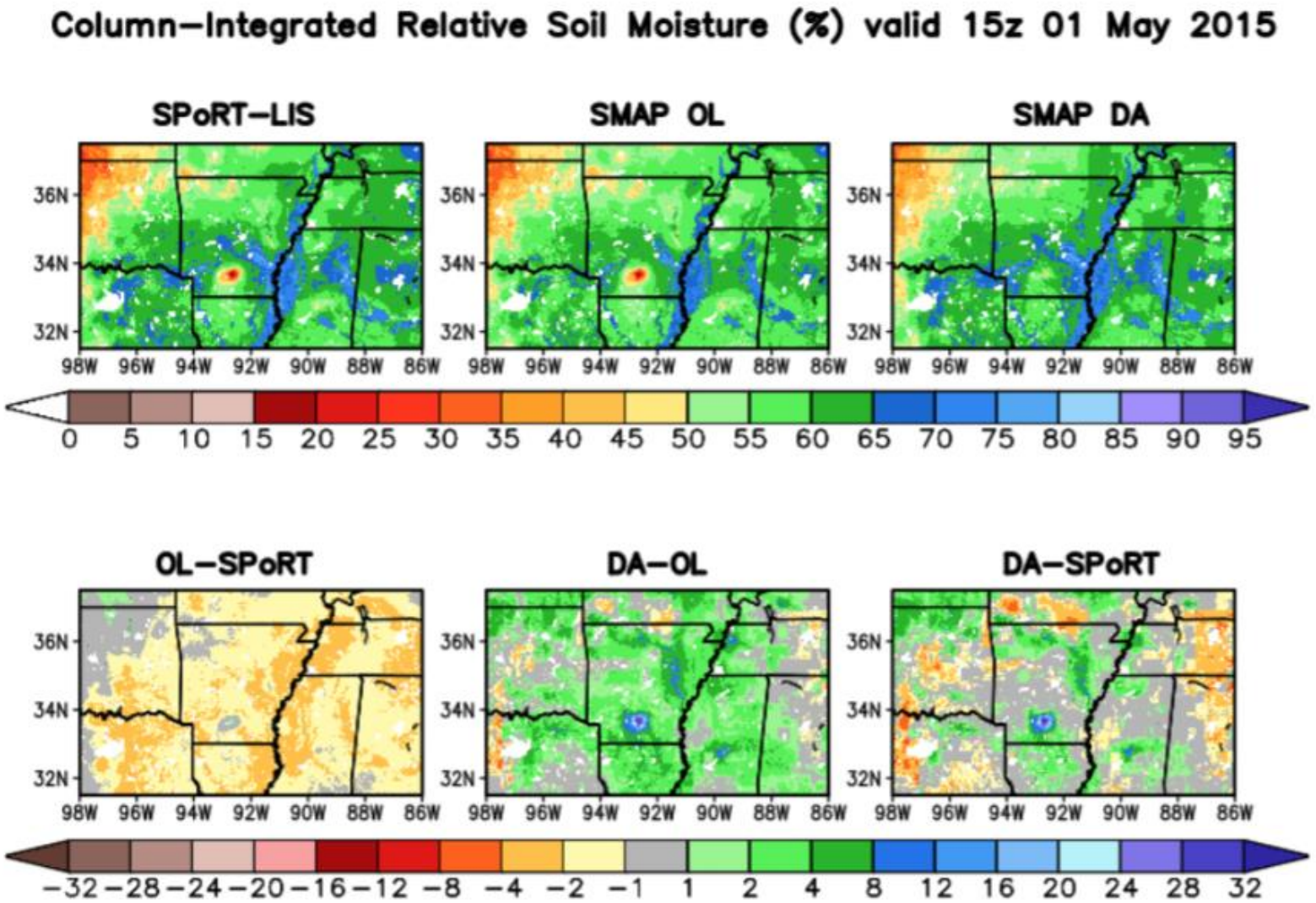


5. Analysis 12Z 1Apr2016

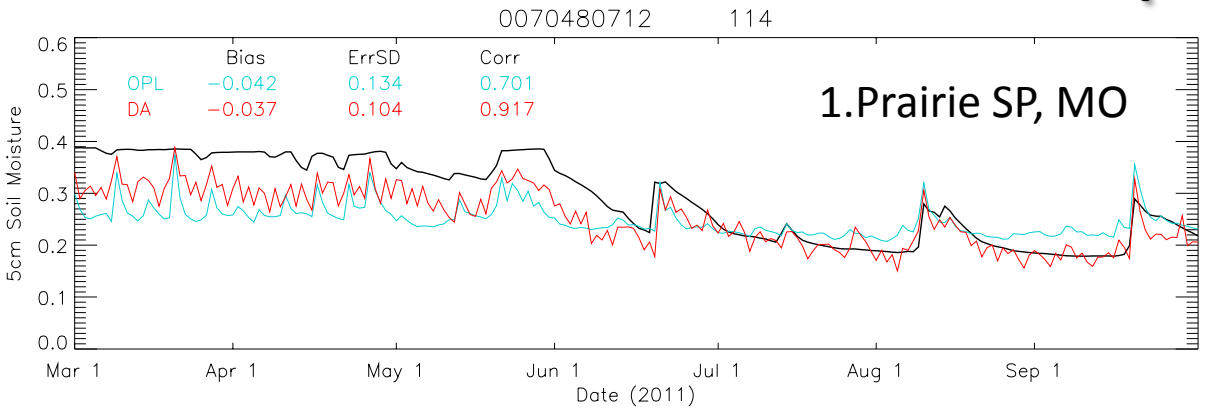


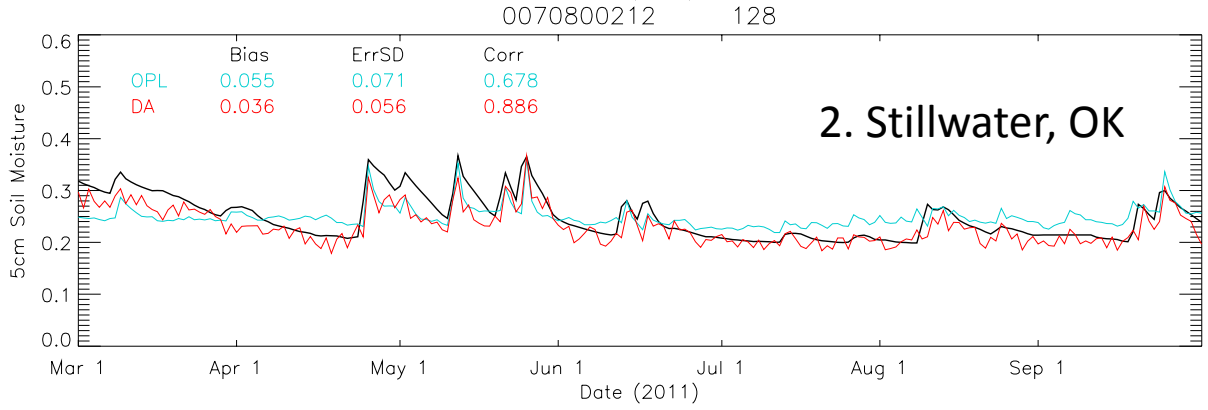
1. LIS Background Soil Moisture (0-10 cm)
2. SMAP Observed SM *(after QC)*
3. Innovation *(Ob minus Bk)*
4. Model Increment
5. Model Analysis *blending background and obs*

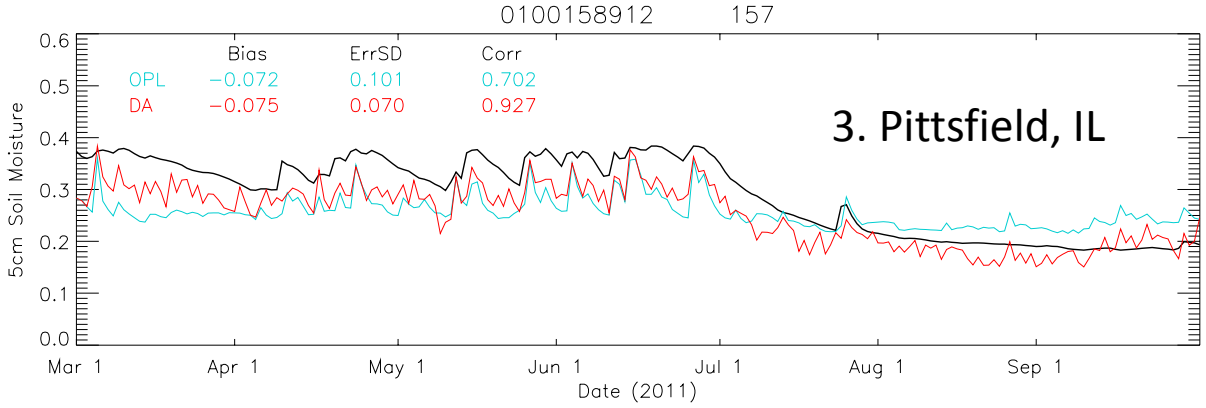
Reduction of errors in forcing data

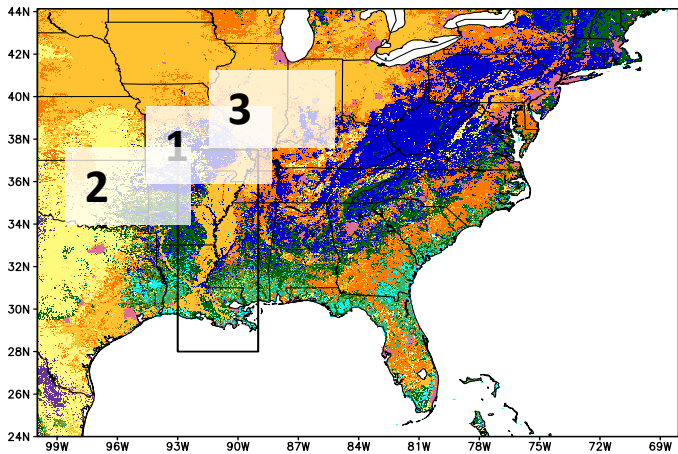


Validation Results (SMOS DA)







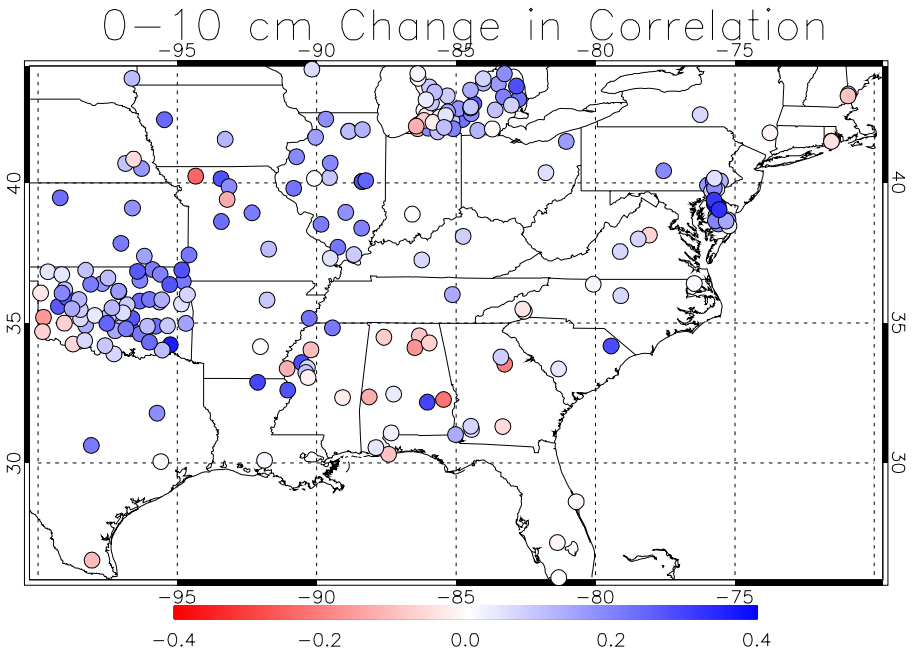


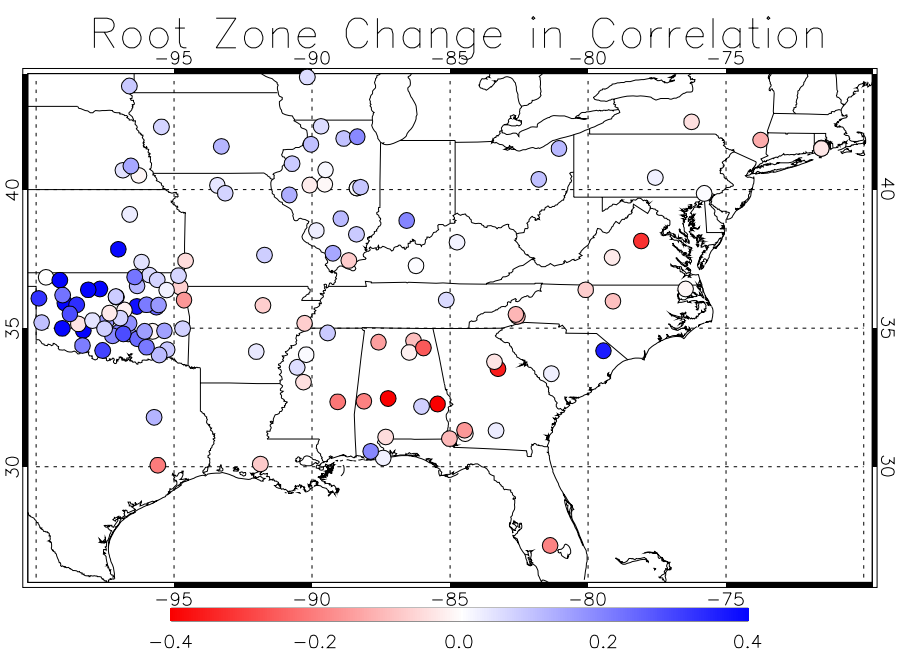
- 0-10 cm model soil moisture
- Compared open loop run to SMOS DA run.

Results from validation against soil moisture networks in US (North American Soil Moisture Database)

- Better correlations
- Improved dynamic range

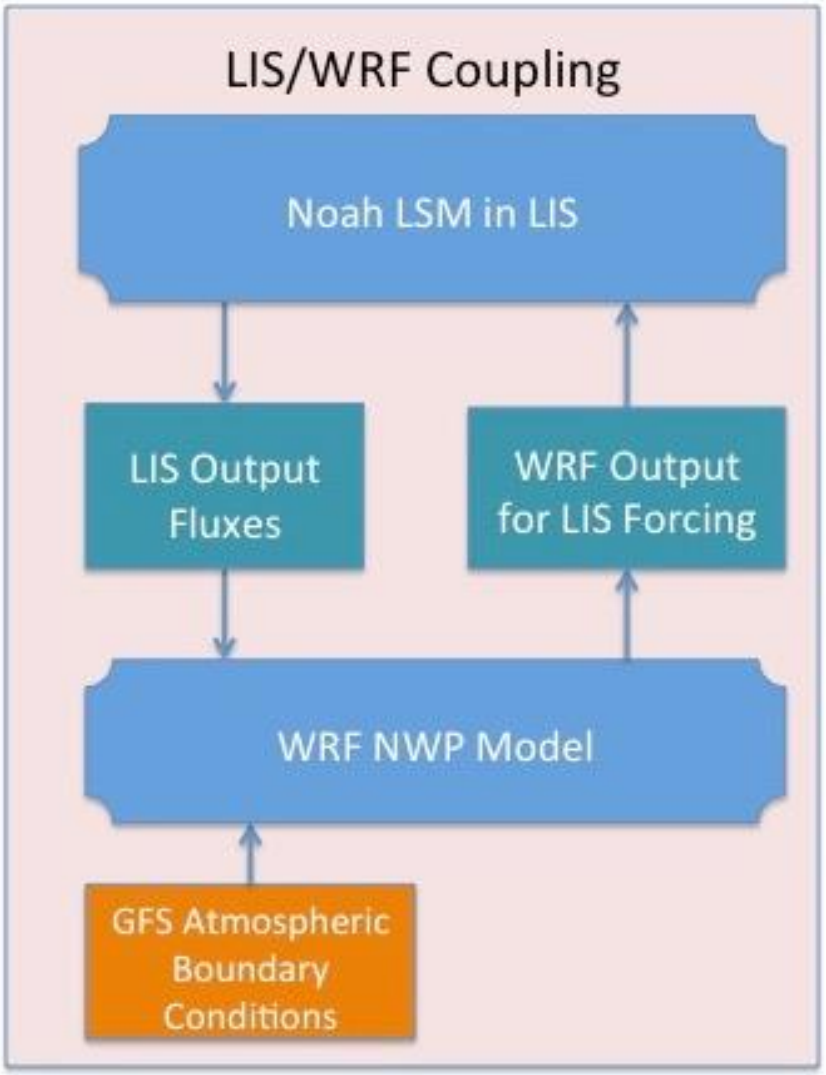
Validation Results (SMOS DA)





	Near Surface (0-10 cm)			**Root Zone (10-100 cm)**		
	Bias	Err SD	**Corr.**	Bias	Err SD	**Corr.**
Control	3.6%	23.5%	**0.47**	4.0%	10.6%	**0.61**
SMOS DA	-0.5%	21.8%	**0.57**	10.6%	11.8%	**0.67**

WRF impact tests (planned)



- Coupled LIS/WRF runs within NASA Unified WRF (NU-WRF)
  - NWP provides forcing for LSM
  - LSM provides fluxes and surface conditions to NWP model
- Assess impact of SMAP DA on NWP for coupled runs
  - Verify NWP forecasts against surface obs, soundings, and precipitation analyses
  - Examine impact on significant events

Validation Datasets		
Domain	**T, q, wind**	**Precipitation**
CONUS	MADIS	MRMS
East Africa	WMO network	GPM IMERG

Future Plans

Assimilate SMAP over CONUS (implemented) and East Africa (in progress)

Validation against ground stations (including dense networks and COSMIC probes)

Perform LIS/WRF coupled modeling experiments within NU-WRF

Evaluate impact on short-term (48h) NWP fields

Expect more dramatic improvement over Africa where observing networks are less extensive.

Planned Improvements

- Continue to refine bias correction, perturbations, and other settings
- Test assimilation of 9-km enhanced SMAP product
- Test use of additional thinner surface layer in model
  - Expect more dramatic improvement over Africa where observing networks are less extensive.
- Possible use for fire risk assessment
- WRF-Hydro and integration with streamflow prediction

Questions and Comments?

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